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Technical Note on Scale Conversion for the Synchronous Impulse Reconstruction (SIRE) Radar, a Second Method

by Kenneth Ranney, Lam Nguyen, and Anders Sullivan

ARL-TN-0287 **July 2007**

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14. ABSTRACT

This technical note describes a calibration method used to convert measurements obtained with the U.S. Army Research Laboratory (ARL) synchronous impulse reconstruction (SIRE) radar from an integer scale to an absolute, radar cross section (RCS) scale. The required RCS reference point is obtained from highly accurate solutions of Maxwell's equations for a modeled reference target and scene. Electrical characteristics of this modeled target and scene are carefully selected to match those encountered in the actual data collection. The method described here differs slightly from that described in "Technical Note on Scale Conversion for the Synchronous Impulse Reconstruction (SIRE) Radar," ARL-TR-0286. The newer method uses a peak-matching technique, while the earlier version used an energy-conservation technique.

15. SUBJECT TERMS

Ultrawideband impulse radar, radar calibration, SIRE

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Introduction

A well-understood, absolute measurement scale plays a critical role in understanding the physical phenomena observed in radar data. Such a scale provides a common reference frame and enables comparison of synthetic aperture radar (SAR) data collected from multiple radar sensors. For this reason, the Synchronous Impulse Reconstruction (SIRE) radar team wishes to determine a scale factor that allows measurements expressed in a scale based on analog-to-digital (A/D) counts to be converted to radar cross section (RCS) values.

In many applications, a particular reference target of known RCS, typically a point-like target, is placed in-scene to provide a calibration reference signal. The RCS of this reference target has been determined theoretically and, therefore, provides a reference number for scaling the corresponding target response observed in SAR imagery. If, however, a theoretical number is not available for a particular reference target, then a different approach is required. The extremely low depression angles inherent in the SIRE radar operation make the classical theory-based approach impractical. Thus, we have implemented a unique mixture of high fidelity electromagnetic (EM) modeling results and data measurements to obtain the desired calibration scale factor. In a previous report,[1] a solution was developed based on an initial set of underlying assumptions. However, we have developed another approach, which is described in this report, that is based on a second, slightly different set of underlying assumptions.

Technical Approach

As mentioned above, we have used results from high fidelity electromagnetic models and EM-solvers in conjunction with measured radar data to obtain a calibration factor for the SIRE radar. This factor maps image pixels within the focused SAR image from their original values into commonly used RCS values.

In order to obtain the necessary RCS reference point, we select a canonical target deployment and model both the target and the SIRE radar system (i.e., frequency band and operational geometry). Using high fidelity EM-solvers developed at ARL, we then solve for the RCS of the canonical target at many individual frequencies within the frequency band of interest. Since the solvers yield both a magnitude and phase at each frequency, we are able to filter the outputs as desired. That is, we can match signal peaks in the modeled signatures to those observed in the actual data collection. Unlike our earlier technique, that invokes Parseval's theorem to relate the

[1] "Technical Note on Scale Conversion for the Synchronous Impulse Reconstruction (SIRE) Radar," ARL-TN-0286.

total energy reflected by the canonical target in both the modeled and measured cases, our new method utilizes a peak-matching strategy. We believe that, for the processed image, this approach requires assumptions that more accurately reflect the observed physical phenomena.

As part of this approach we make the following approximations that allow us to relate radar measurements to results obtained using the EM-solvers:

a. The time domain response due direct-path reflections from the sphere surface approximates a point target.

b. Due to symmetry, the direct-path response due to the sphere will be similar for all transmitter-receiver combinations.

c. Any signal contributions due to multi-path will be separable from the main-bang effects. That is, they will not contribute to the signal reflected directly from the surface of the sphere.

d. The focusing procedure is linear and provides adequate cross-range resolution to isolate the canonical target from any neighboring background clutter.

e. Due to symmetry, the measured sphere RCS from the direct path will not be affected by integration in the direction that the vehicle travels (i.e., along-track integration).

If the above relationship holds, then we calculate the scale factor, α, that converts the native A/D measures into RCS according to the formula:

$$\alpha = \frac{\max\limits_{m=1,\ldots,N_{\text{modeled}}} \left\{ \left| f_{\text{modeled}}(m) \right|^2 \right\}}{\max\limits_{n=1,\ldots,N_{\text{measured}}} \left\{ \left| f_{\text{measured}}(n) \right|^2 \right\}},$$

where N_{modeled} represents the number of frequency samples used from the modeled response (as determined by the bandwidth used to form the focused image), N_{measured} represents the number of measured down-range samples considered in the vicinity of the sphere signature, and $f_{\text{modeled}}(m)$ and $f_{\text{measured}}(n)$ represent the modeled and measured high resolution profiles, respectively.

We note here that the scale factor, α, obtained in this way may change as the bandwidth used to obtain the focused imagery changes. Thus, we will calculate a new scale conversion factor for each bandwidth of interest based on modeled and measured data. We also note that the results obtained in this manner may differ by about 3 to 4 dB relative to those obtained using the earlier method when the modeling result predicts a large multi-path effect that is not observed in the actual data.

Finally, it should also be noted that the focused imagery examined here does not include integration along the vehicle's direction of motion. We assume (see d above) that this will not affect the observed peak due to the direct-path reflection from the surface of the sphere.

The appendix includes examples of down-range cuts from focused SIRE imagery together with the calibration factor calculated for each case. The table in the appendix compares the results obtained using the method described above with those obtained using the earlier method. Additional imagery is available in the initial report mentioned in the Introduction.

Summary

This technical note described a method for converting radar measurements from a scale based on A/D output values to a universal scale based on RCS. The desired conversion factor is obtained by exploiting a "peak-matching" strategy together with a few simplifying assumptions. For this reason, it is valid only for the bandwidth used to obtain a particular focused image. It can easily be applied to any image of interest, however, provided that both modeled and measured data exist. It is the incorporation of outputs from high fidelity EM-solvers that differentiate the proposed method from many methods commonly used in practice.

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Appendix. Examples of Calibration Factors Calculated for Various SIRE Images

For additional imagery, see the earlier technical note, “Technical Note on Scale Conversion for the Synchronous Impulse Reconstruction (SIRE) Radar,” ARL-TN-0286.

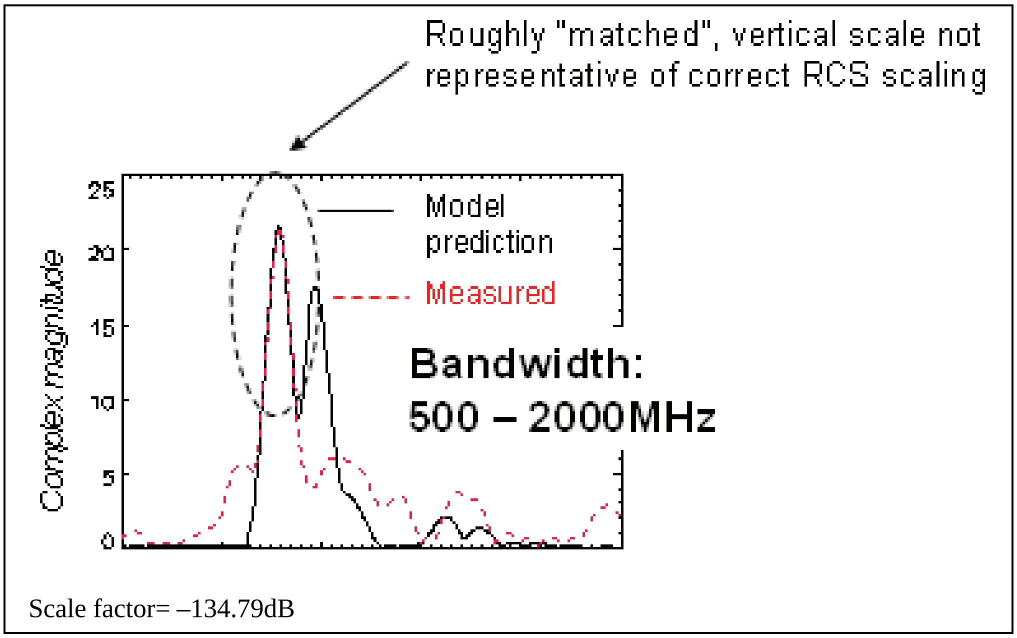

Figure A-1. Image bandwidth 500–2000 MHz.

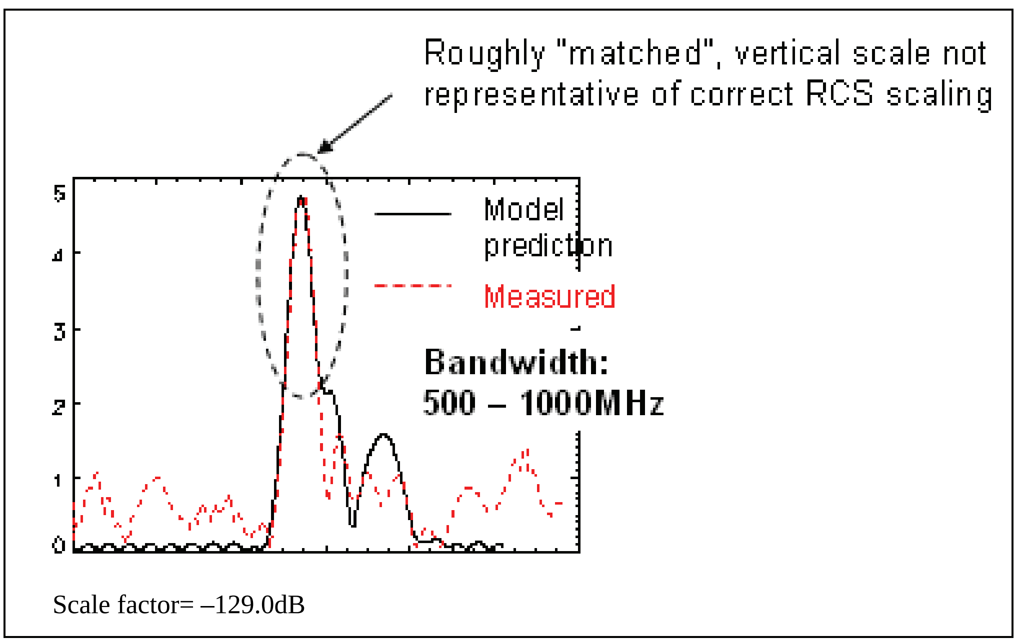

Figure A-2. Image bandwidth 500–1000 MHz.

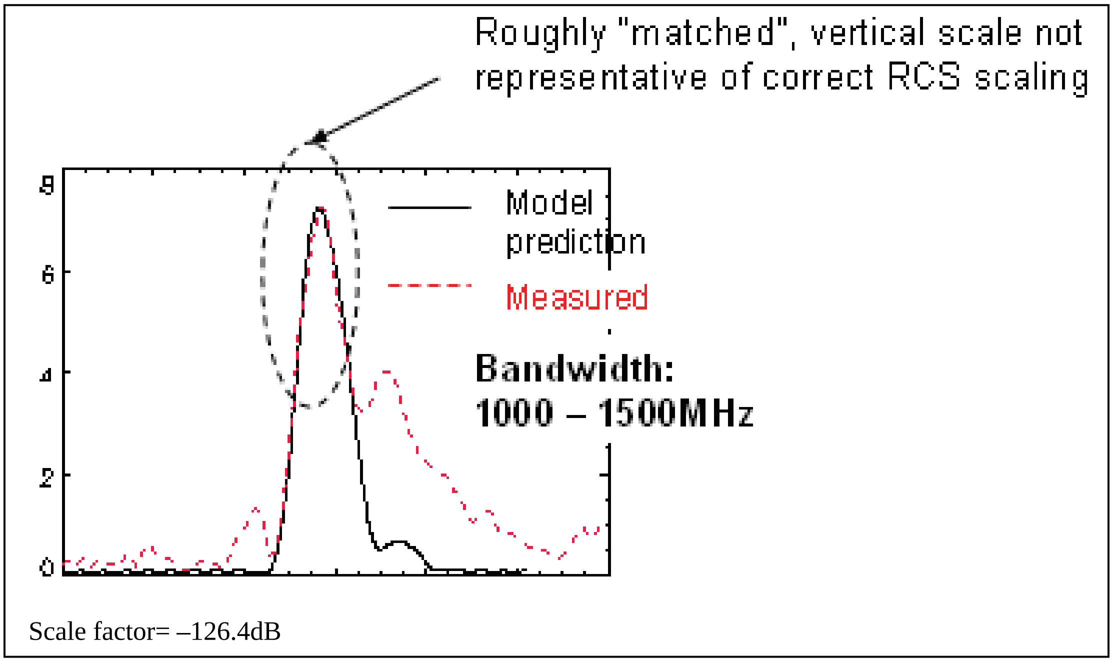

Figure A-3. Image bandwidth 1000–1500 MHz.

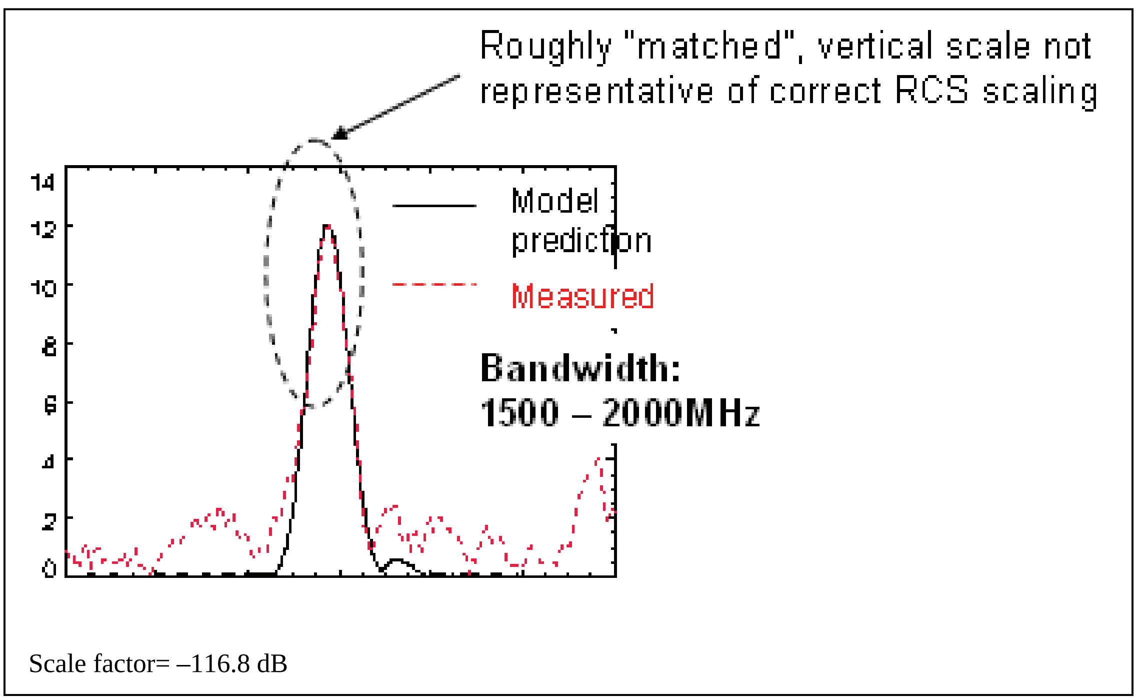

Figure A-4. Image bandwidth 1500–2000 MHz.

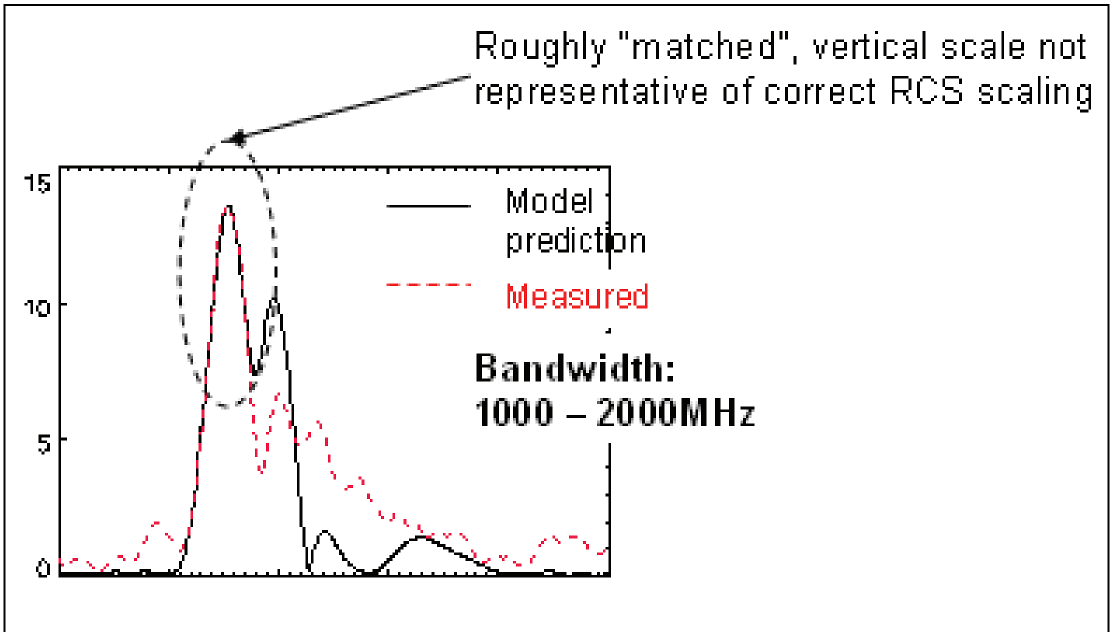

Figure A-5. Image bandwidth 1000–2000 MHz.

Below is the comparison on scale factors for two methods. The large difference for 500 to 2000 MHz is due to the large multi-path "second peak" predicted by the model that was not observed in the focused data. Note that the "Sphere RCS" values stored in the table are the values corresponding to the ***peak in the measured data*** after the scale factor has been applied.

Band (MHz)	Scale Factor, Method 1	Sphere RCS, Method 1	Scale Factor, Method 2	Sphere RCS, Method 2	Scale Difference
500–2000	–131.0dB	–1.3 dBsm	–134.8dB	–5.1 dBsm	–3.8 dBsm
500–800	–125.5dB	–5.7 dBsm	No data	No data	No data
500–1000	–127.7dB	–3.1 dBsm	–129.0 dB	–4.4 dBsm	–1.3 dBsm
1000–1500	–123.9dB	–1.2 dBsm	–126.4 dB	–3.7 dBsm	–2.5 dBsm
1500–2000	–115.1dB	–0.1 dBsm	–116.8 dB	–1.9 dBsm	–1.8 dBsm
1000–2000	–125.3 dB	–0.58 dBsm	–128.1 dB	–3.4 dBsm	–2.82 dBsm

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